

The Agricultural and Mechanical College of Texas
Department of Oceanography
College Station, Texas

Texas A & M Research Foundation
Project 59

PROGRESS REPORT FOR
QUARTER ENDING DECEMBER 31, 1952

Project 59 has as its objective the measurement of heat, momentum, and water flux from the sea surface. It is sponsored by the Office of Naval Research (Project NR 083-084, Contract N7onr-487, Task Order 5). The work reported herein is of a preliminary nature.

Report prepared February 16, 1953
by
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John C. Freeman, Jr., Project Supervisor

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I. Aims:

The general aims of the project are:

- A. To develop instrumentation suitable for the measurement of the flux of heat, momentum, and water vapor from the sea surface, if possible by more than one method.
- B. To obtain a sufficient number of measurements of these fluxes to draw quantitative conclusions about the factors involved.

II. Instrumentation.

A. Requirements:

- 1. "Intimate structure" approach. This approach makes use of the relations

$$\begin{aligned} F_M &= \rho \overline{UW} \\ F_H &= c_p \rho \overline{WT} \\ F_W &= \rho \overline{Wq} \end{aligned}$$

where F_M , F_H , and F_W are vertical fluxes of momentum, heat, and water vapor, respectively. ρ is density, U and W are horizontal and vertical components of the wind, c_p is the specific heat of the air at constant pressure, T is the temperature, and q is the specific humidity.

The instrumentation required must measure horizontal wind velocity, vertical velocity, temperature, and specific humidity continuously with time resolution sufficient to accurately represent all eddies of transporting size. It is estimated, on the basis of past experience, that this resolution should be 0.1 sec or better. Some investigation will be necessary to determine the resolution necessary.

Since the instruments will be exposed to a corrosive atmosphere at some distance from laboratory facilities, extreme durability is called for. Frequent recalibration will be impracticable. These requirements rule out hot-wire type instruments, notorious for their fragility and instability.

Nearly all current instruments used in this type of measurement present their results as separate continuous traces of temperature,

humidity, total wind, and angle of wind. The labor of transcribing the data and performing subsequent calculations becomes extremely tedious. One group estimates a month of calculation for each ten minutes of observation! Thus, if any significant amount of data is to be obtained, it is imperative that essentially all computation be performed automatically. Electronic techniques exist for accomplishing this end if the instrumentation presents its results in linear or other simple form. The requirement also discourages the use of hot-wire anemometry.

2. Heat budget approach. This makes use of the heat budget of the water,

$$R + A = H + E + S$$

where R is the net radiation flowing into the water surface, A is the heat added by advection of water, H is the sensible heat flux from the surface, E is the heat loss by evaporation, and S is the heat stored in the water and sea bottom. R may be obtained from a net radiometer, A from observation of currents and horizontal sea temperature gradients, S from sea temperature profiles, and H and E would then be found by subtraction. They can be separated by the Bowen Ratio technique, making use of measurements of gradients of temperature and humidity. The measurement of temperature gradients can be obtained from thermocouple circuits, with some difficulties. Humidity gradients present some problems, but might be handled by aspirated thermocouple psychrometers.

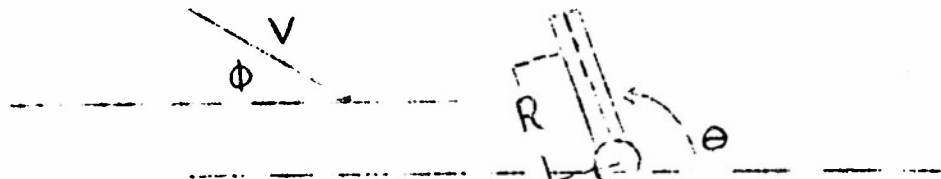
3. Profile approach. This makes use of the form of the vertical profile of wind, temperature, and humidity, from which fluxes may be deduced. The problems of measuring profiles are well known. There appears to be some doubt as to the applicability of this method over a sea surface, and some investigation must be done before attempting to use this approach.

B. Instrumentation to be used:

It is planned to proceed first with the "intimate structure" approach. The instrumentation planned is:

1. Anemometer. In place of the Swinbank hot-wire instrument, it is planned to proceed with the development of a new type of instrument, the principle of which is as follows:

The rotating-arm anemometer. Let a cylinder be rotated about a horizontal axis perpendicular to its own axis, the plane of rotation to coincide with that of the wind vector.



It is a property of the cylinder that the flow about the frontal node is very nearly potential flow, so that the nodal pressure is $\frac{1}{2} \rho V_n^2$ where V_n is the component of the flow normal to the cylinder.

If the cylinder is rotating at angular velocity ω and has a pressure hole in the leading edge at radius R from the axis of rotation, the relative wind normal to the cylinder due to the rotation is ωR . The component of the actual wind perpendicular to the axis of the cylinder is $V \sin(\phi + \theta)$, where V is the instantaneous wind speed, ϕ is the elevation of the wind vector, and θ the angle of the axis of the cylinder with respect to the horizontal. (See Figure) Now let $\theta = \omega t$. The pressure on the hole will be given by:

$$\begin{aligned} p &= \frac{1}{2} \rho [\omega R + V \sin(\phi + \omega t)]^2 \\ &= \frac{1}{2} \rho [\omega^2 R^2 + 2\omega R V \sin(\phi + \omega t) + \frac{V^2}{2} - \frac{V^2}{2} \cos 2(\phi + \omega t)] \\ &= \frac{1}{2} \rho [\omega^2 R^2 + 2\omega R V \sin \phi \cos \omega t + 2\omega R V \cos \phi \sin \omega t + \frac{V^2}{2} \\ &\quad - \frac{V^2}{2} \cos 2\phi \cos 2\omega t + \frac{V^2}{2} \sin 2\phi \sin 2\omega t] \end{aligned}$$

If the pressure is measured by a linear transducer, the voltage output will be the pressure times a factor of proportionality α . Let us now multiply αp by $\sin \omega t$, using a resolver with appropriate carrier, and then integrate by appropriate circuitry. We will make use of the relations

$$\begin{aligned} \lim_{T \rightarrow \infty} \int_0^T \sin at \sin bt \, dt &= \lim_{T \rightarrow \infty} \int_0^T \cos at \cos bt \, dt \\ &= \lim_{T \rightarrow \infty} \int_0^T \sin at \cos bt \, dt = 0 \quad \text{if } a \neq b \text{ for the first two.} \\ \int_0^T \sin^2 at \, dt &\cong \int_0^T \cos^2 at \, dt \cong \frac{T}{2} \end{aligned}$$

then

$$\int_0^T \alpha p \sin \omega t dt = \frac{1}{2} \alpha \rho \omega R V T \cos \phi$$

$$\frac{1}{T} \int_0^T \alpha p \sin \omega t dt = \frac{1}{2} \alpha \rho \omega R V \cos \phi$$

if V and ϕ do not have harmonic components of angular velocity (ω) and constant phase.

$V \cos \phi$ is the horizontal velocity; its multiples are near constants.

Similarly, let us multiply αp by $\cos \omega t$ and integrate:

$$\frac{1}{T} \int_0^T \alpha p \cos \omega t dt = \frac{1}{2} \rho \omega R V \sin \phi$$

where $-V \sin \phi$ is of course the vertical velocity.

Finally, let us multiply αp by $\sin 2\omega t$ and integrate as before.

$$\frac{1}{T} \int_0^T \alpha p \sin 2\omega t dt = \frac{\alpha}{4} \rho V^2 \sin 2\phi$$

but $V^2 \sin 2\phi = 2V^2 \sin \phi \cos \phi$

$$\text{so } \frac{1}{T} \int_0^T \alpha p \sin 2\omega t dt = \frac{1}{2} \rho (V \sin \phi)(V \cos \phi) = \frac{1}{2} \alpha \rho u w$$

where u and w are horizontal and vertical velocities. The shearing stress is given by $\overline{p u w'} = \overline{p u w} - \bar{p} \bar{u} \bar{w}$, so the quantity $\frac{\alpha}{2} \rho u w$ may be taken as a measure of shearing stress.

If the multiplication be by the factor $T \cos \omega t$ where T is temperature, we have

$$\frac{1}{T} \int_0^T \alpha p T \cos \omega t dt = \frac{1}{2} \alpha \rho \omega R \omega T$$

The quantity $\rho \omega T$ is the vertical heat flux.

The same process may be used with χ , the mixing ratio, for vertical water vapor fluxes.

Let us introduce some figures. Let V be 5 m/sec = 500 cm/sec. Let $\omega R = 1000$ cm/sec, so that $\rho \omega R = 1$. The first harmonic pressure fluctuation will be of the order $500 \text{ dynes/cm}^2 = \frac{1}{2} \text{ mb}$. This is adequate for transduction of good accuracy (far above sound pressures).

The second harmonic will be around 60 dynes/cm² amplitude, which with care can be utilized. Higher winds would call for higher values of ωR with correspondingly much higher pressures.

If the shaft rotate at 20 r.p.s., $\omega \cong 130/\text{sec}$ and R would be about 8 cm. A pencil-shaped cylinder, perhaps slimmer than a pencil, is indicated. To avoid end effects, the cylinder must be considerably longer than R — perhaps $1.5 R$.

The same principle would apply to a water current meter which would record velocity and direction of current, even at low values. As a current meter, the arm would rotate in a horizontal plane. For currents up to 1 knot, = 50 cm/sec, the arm might rotate at $\omega R = 100$ cm/sec. The pressures would be of amplitude 50 dynes/cm² for each cm/sec. One knot would produce an amplitude of 2500 dynes. Suggested values are $R = 100$ cm, $\omega = 1$, $2\pi\omega = 6$, or one revolution per six seconds.

The principle of operation of this instrument was developed by Dr. Glaser while employed by the Department of Meteorology of the University of Wisconsin on an Air Force contract. It is understood that that contract does not intend to proceed with development of the instrument.

2. Thermometer. A small thermistor type, with output amplified and response speeded as recommended by Doyle. The output would be used as an electronic multiplier of the vertical velocity.

3. Humidity. A Swinbank-type circuit, possibly modified for use with thermistors, with response speeded electronically.

4. Temperature gradients. For the present the measurements made by a cooperating project will be used.

5. Wind profiles. Instruments set up by a cooperating project will be used.

III. Personnel.

Dr. Arnold H. Glaser joined the project as Chief Scientist at quarter time on 24 December 1952 and will go on full time on 10 January 1953. He will proceed with the development of the instrumentation. Dr. Glaser's biographical sketch is attached.

Full Name	GLASER, ARNOLD HENRY
Born	Mount Vernon, Washington, 1919
Training	<p>University of Washington, 1936-40, B. S. Major - physics; minor - chemistry</p> <p>University of Washington, 1941, M. S. Major - physics; minor - mathematics</p> <p>Massachusetts Institute of Technology, 1941-42, 1948-50, 1952, Sc. D., Major - meteorology</p> <p>Imperial College of Science and Technology (London), 1951, Diploma, Major - meteorology</p>
Experience	<p>Pan American-Grace Airways, Lima, Peru, 1942-3, airways fore- caster, research in statistical weather forecast methods.</p> <p>Lloyd Aereo Boliviano (Bolivian National Airline), Cochabamba, Bolivia, 1943, Chief Meteorologist.</p> <p>U. S. Army Air Force, 1944-45, assistant long range forecaster, Principal Instructor in Aerial Weather Reconnaissance.</p> <p>Ministry of Air, Brazil, Escola Tecnica de Aviacao, Sao Paulo, 1946-48, instructor in meteorology.</p> <p>Massachusetts Institute of Technology, Cambridge, Massachusetts, 1948-49, organization of U. S. Weather Bureau- MIT Southern Hemisphere map analysis project.</p> <p>Brookhaven National Laboratory, Upton, New York, 1950, Research Associate, research in atmospheric turbulence and diffusion.</p> <p>Imperial College of Science and Technology, London, England, 1950-51, research in applied aerodynamics and meteorological instrumentation.</p> <p>University of Wisconsin, Madison, Wisconsin, 1952-53, Project Associate, research in electronic instrumentation for micrometeorology.</p> <p>Texas A. & M. College, Department of Oceanography, 1953- , Assistant Oceanographer (Meteorological), research in meteorology and oceanography.</p>
Organizations	<p>Sigma Xi</p> <p>American Meteorological Society (professional member)</p> <p>Royal Meteorological Society (foreign member)</p>
Awards	<p>Massachusetts Institute of Technology scholarship, 1942</p> <p>Gerard Swope Fellowship, 1949-50</p> <p>Fulbright Scholarship, 1950-51</p> <p>Massachusetts Institute of Technology - Imperial College Exchange Fellowship, 1950-51</p>
Publications	<p>"Solar and Sky Radiation," M.S. Thesis and Bul. Amer. Meteor. Soc., 1941.</p> <p><u>Tropical Meteorology</u>, Bonnot, Conger, Duncan, and Glaser, USAAF TM, 1944.</p> <p>"The Pitot cylinder as a static pressure probe in turbulent flow," J. Sci. Inst. 29: 219-221, 1952.</p>

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